Human Factors Engineering at Marshall Space Flight Center

Mariea C. Dunn, Ph.D.
Research Fellow and Assistant Professor
NASA Marshall Space Flight Center and Southern University and A&M College
MC EO66, MSFC, AL 35812
mariea.dunn@msfc.nasa.gov
and
Sonya L. Hutchinson
Systems Engineer
NASA Marshall Space Flight Center
MC EO66, MSFC, AL 35812
sonya.hutchinson @msfc.nasa.gov

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Abstract

The mission of NASA Marshall Space Flight Center (MSFC) is to develop, implement, and maintain systems for space transportation and microgravity research. Factors impacting the MSFC position as a leader in advancing science and technology include: 1) heightened emphasis on safety; 2) increased interest in effective resource utilization; and 3) growing importance of employing systems and procedures that pragmatically support mission science. In light of these factors, MSFC is integrating human factors engineering (HFE) into the systems engineering process. This paper describes the HFE program, applications of HFE in MSFC projects, and the future of HFE at MSFC.

Introduction

The mission of the National Aeronautics and Space Administration (NASA) Marshall Space Flight Center (MSFC) encompasses Space Transportation Systems and Microgravity Research. Specifically, MSFC is responsible for developing, implementing, and maintaining systems to transport humans into space to conduct multifarious scientific research. Recently, MSFC has recognized some factors impacting its position as a leader in advancing science and technology: 1) heightened emphasis on safety; 2) increased interest in effective resource utilization; and 3) growing importance of employing systems and procedures that pragmatically support mission science. Successfully achieving the MSFC mission while navigating these factors mandates that an effective systems engineering process be followed. To this end, MSFC is emphasizing the integration of human factors engineering (HFE) into the systems engineering process.

A clear understanding of the importance of HFE to the systems engineering process requires first an understanding of the terms. First, consider systems engineering. The definition composed by Budurka [2] appropriately describes the position taken at MSFC:

> System engineering is the iterative but controlled process in which user needs are understood and evolved, through incremental development of requirements specifications and system design, to an operational system. Systems engineering includes the control and integration of all disciplines throughout the system life cycle in a manner so as to assure that all user requirements are satisfied. [p.41]

Indeed, the systems engineering process followed at MSFC is an interdisciplinary, iterative approach to design. HFE is but one of a variety of disciplines working collaboratively to accomplish the mission of the Center.

Note that HFE is a relatively new branch of engineering that has received some scrutiny, but continues to prevail as a vital component of project life cycles. Although this branch of engineering goes by other monikers like *human factors, ergonomics,* and *human engineering*, the term *human factors engineering* (HFE) conveys the focus on science and engineering principles in the practice of HFE. HFE may be defined as the development and systematic application of scientific and engineering principles and data in the analysis, design, and evaluation of tools, equipment, tasks, systems, and environments for safe, efficient, and effective human use. Simply stated, HFE stresses human-centered design.

One source proposes breaking the HFE definition into 3 prongs: focus, objective, and approach. [6] The focus of HFE is on human beings and their interaction with products, equipment, facilities, procedures, and environments. The objectives are to optimize total system performance, ensure safety, and enhance comfort and convenience. Cursory consideration of these objectives may indicate that they are difficult to achieve in tandem; however, a consolation is that in practice, the objectives usually are correlated. For example, improving safety may also increase comfort and functionality. The HFE approach is to systematically apply to the design process relevant information about the human component, thereby complementing iterative design.

This paper presents HFE as it should be incorporated into the systems engineering process at MSFC. Because HFE is a relatively new field of engineering, the integration process at MSFC is in its infancy. The next section describes an idealized HFE process flow as proposed by the Systems Branch of the Mission Operations Laboratory. This branch consists of a team of human factors engineers who are responsible for HFE tasks. The paper then presents a discussion of the HFE methods and tools commonly used at MSFC and descriptions of some MSFC projects in which HFE has been applied. The final section summarizes and closes the paper with a glimpse of the future of HFE at MSFC.

HFE Process Flow

Figure 1 (see Appendix) depicts the HFE process flow as integral to each phase in the systems engineering process. [1] The first two phases focus on understanding the project mission and system characteristics such as architecture, operations, logistics, and support criteria. Here, a project team 1) determine what is to be produced and/or launched into space and 2) define the supportability and supportability-related design parameters. During the preliminary analysis phase, the HFE activity is to identify the intended users and their needs. At the definition phase, HFE supports delineation of system functions to be performed in meeting system objectives by ensuring that functions meet the needs of the intended users (astronaut crew members). This will involve collecting detailed information on the characteristics, capabilities, and limitations of the intended users. Two outcomes of these initial stages are a systems engineering management plan and a risk management plan.

The design and development phases are the points at which the system begins to take shape in the form of prototypes and fabrications for testing, integration, and verification. The HFE activities focus on allocation of functions among the human component, hardware, and software. Functions allocated to the human component must be designed to adequately support human performance of these functions. Consequently, the HFE tasks are to assess and make trade-offs among factors like safety, cost, utility, and human physical and cognitive support. Unfortunately, there are no rigid guidelines for making such allocations. The engineer must rely on accepted human factors standards and guidelines as strategies rather than strict rules, and make decisions based on the consideration of those factors most pertinent to the particular project. For example, management characteristics, mission requirements, crew member preferences, and budget and time constraints often impact function allocation. Culminating the development phase is the production of a workable system.

The final phase is the operations phase, during which the system is used for its intended purpose. The HFE activities fall under maintainability, supportability, upgrading, and disposal. HFE may involve identifying the how, when, and why associated with each of these activities.

The next section describes some of the techniques and tools used in the HFE process.

HFE Techniques and Tools

Typically, HFE analyses target human interfaces within systems. In design of systems for manned space flight and microgravity research a number of human interfaces may be subject to human factors considerations. Table 1 groups these interfaces into categories. Functional interfaces include envelopes, forces, and restraints. Visual and reach envelopes represent the work space encountered by crew members, while operating forces are those forces that affect human function in the microgravity environment. Examples of crew and equipment restraints are tethers, fasteners, and quick connects and disconnects. Tethers are used to secure crew members and their tools during flight or space walks. Fasteners and quick connects and disconnects serve a variety of joining and disjoining purposes in space hardware.

Another category of human interfaces is human-computer interaction. Data displays and controls are those visual, manual, verbal and auditory means of interfacing with computer systems. System response characteristics also support human-computer interaction. The third category of interfaces lists aesthetic aspects of systems, such as illumination, acoustics, and cues and labeling.

CATEGORY	HUMAN INTERFACES
Functional	Visual envelope
	Reach envelope
	Operating forces
	Crew restraints
	Equipment restraints
Human-computer interaction	Data displays
	Controls
	System response characteristics
Aesthetics	General illumination
	Task illumination
	Acoustics
	Cues
	Labeling
Other	Stowage definition

Table 1. Typical Human Interfaces

For each of these categories of human interfaces and for each aspect of the HFE process there exist methods and/or tools for performing analyses and making design decisions. This section presents those most prominently employed in the HFE work at MSFC: human modeling, functional flow and task analysis, and usability assessment.

Human Modeling

Human modeling is frequently employed in HFE tasks because of its applicability to a broad range of HFE evaluations and because of the quality and detail of the data that can be gathered. Nearly all of the human interfaces previously described are evaluated with this tool. Human modeling involves using a computer simulation software to develop a model of the system or system component with the human component inserted. This simulation is then manipulated to perform necessary analyses. Human modeling packages allow the engineer, using standard anthropometric dimensions, to create a human model of a variety of body forms. The engineer also can simulate realistic joint motion and movement. The human model is inserted into the CAD rendering of the system or component being evaluated.

The Human Engineering and Analysis Team (HEAT) at MSFC has 3 human modeling packages: Transom JACK, Deneb ERGO, and Mannequin Pro. JACK and ERGO can be augmented with peripherals for virtual reality simulations that may be immersive for the user. The immersive virtual reality alternative gives a three dimensional (3D) depiction of the system or system component being studied. A 3D view is more realistic than a 2D view; thereby, the 3D view may provide more detailed human factors information. Mannequin Pro offers only a 2D view, but has the advantage of operating on a less expensive computer platform than do JACK and ERGO. JACK and ERGO are UNIX-based and operate on high-end Silicon Graphics machines, while the Mannequin Pro package operates on a DOS-based IBM-compatible machine.

Functional Flow and Task Analysis

Functional flow and task analysis are traditional, fundamental methods used in human factors analyses. They are commonly used, simple to perform, and result in useful input to critical decisions in the early systems engineering phases.

A function, which generally is taken to be a broadly defined objective or purpose of a system or subsystem, may be tailored to more narrow emphasis through iterations of the design process. Examples of functions are monitoring control panels and information transfer. A functional flow analysis is a HFE method involving defining the flow of various objectives through the proposed system. In the systems engineering process, this involves defining the functions of automation and crew members then allocating functions based on human capabilities and characteristics, system capabilities and characteristics, and sundry costs related to both. This HFE technique is applied beginning in the first phase of systems engineering when the system purpose is formulated.

A task is a behavior or activity that executes or supports a function. Task analysis is an HFE technique for defining the tasks that must be performed, the information required, and the decisions that affect performance. Tasks analyses are performed for both the automation and the human component as they will be operating in tandem to meet the system objective. The human factors engineer will want to gather data on the physical and cognitive tasks to be performed. Task analyses may occur during all system phases, but in particular at the system definition, design and development phases. The result is a detailed representation of human interaction with system automation.

Both of these human factors analysis methods apply to broad and detailed definition and evaluation of any of the human interfaces in Table 1. The techniques are used to identify the type of interface and its role in the system in view of the human functions and tasks to be performed in system operation.

Usability Assessment

According to the ANSI/HFES Standard, usability may be defined as "the extent to which displays can be used by specified users to implement functions with effectiveness, efficiency, and satisfaction in a specified context of use." Usability assessment, which applies to human-computer interfaces, is used by the HEAT to evaluate a number of principles that should be considered in designing visual displays:

1. Compatibility of system and user's expectations - refers to matching the computer's visual display to the user's mental model or cognitive picture of the task.

2. Consistency and standards - refers to positioning actions in the same physical location, including consistent labels, and providing general means of accomplishing similar functions across displays.
3. Recognition versus recall - relates to ensuring that each display have a distinct appearance that is easily recognized and understood.
4. User control and freedom - concerns path navigation and identification of the relationship between actions involved in maneuvering through displays.
5. Flexibility and efficiency of use - concerns comfortably accommodating both experienced and novice users by allowing shortcuts for efficiency and help support for questions.
6. Error prevention, recognition, diagnosis, and recovery - refers to anticipation and avoidance of probable errors in the design. The design should provide warning messages, allow multiple attempts to recover from errors, and post error messages and suggest corrective actions in plain language.
7. Aesthetic and minimalistic design - concerns inclusion of only that information necessary and relevant to complete current tasks, and presentation of it in a distinctive manner.
8. Visibility of system status - refers to ensuring that the display provides timely feedback for all actions to indicate the system status.

The purpose of usability assessment is to determine the degree to which a display meets these principles. Some commonly used evaluation techniques are 1) heuristic evaluation, 2) conformance to guidelines evaluation, 3) cognitive walkthroughs, and 4) usability testing using a prototype and rapid prototyping tool to capture data.

Applications of HFE at MSFC

Recent applications of HFE include an Extra Vehicular Activity hardware study, an Intra Vehicular Activity hardware study, and the Payload Display Development task.

The Extra Vehicular Activity (EVA) hardware study resulted from the need to improve astronauts maneuvering abilities while wearing the pressurized spacesuit worn in microgravity. In particular, it was necessary to improve the foot restraint positioning on the exterior of the space shuttle cargo bay because of pending missions to deploy a robot arm at the International Space Station. Range of motion was being constrained by inappropriate placement of foot restraints intended to keep the astronaut from floating away from the space shuttle while performing tasks like removing and driving bolts, mating and demating connectors, and actuating levers. Of concern was the provision of adequate visual and reach envelopes.

The human modeling package Transom JACK was used to design and assess the placement of the foot restraints. The model gave data on the visual and reach envelopes, the forces needed to carry out movements and provide leverage for the astronaut during task performance, body position models, and task feasibility. The results were compared with an actual underwater test in which astronauts, equipped with the EVA suits and the modified locations of the foot restraints, performed tasks. The human modeling evaluation proved to be acceptable for 94% of the tasks attempted by the astronauts in the underwater test. Thus, the human modeling package proved to be an accurate tool for design analysis, and a more suitable location for foot restraints was derived. [3]

The Intra Vehicular Activity test involved an analysis of the placement of the laptop computer to be used by astronauts to operate an experimental urine processor or Vapor Compression Distillation Experiment (VCD) on the International Space Station. [5] Based on the literature, engineers found that prolonged operation of the VCD would lead to fatigue and human error, but that this could be alleviated with proper positioning of the laptop. Positioning of the laptop was dependent upon placement of floor mounted loops or foot restraints to harness the astronaut while working at the laptop.

A model of the VCD and laptop with a human avatar was developed using Transom JACK. Desirable features of JACK were the ability to adequately simulate micro-gravity, provision of the line-of-sight feature for visual envelope analysis, and accurate representation of human joint movement. The model provided information on visual and reach envelopes and motion constraints. The data was used to determine the angles and distance away from the VCD at which to place the foot restraints so as to achieve a suitable comfort level for the user.

The Payload Display Development (PDD) task is currently underway, and has a significant role in MSFC operations because it directly relates to microgravity research. Its function is to increase usability across the many computer visual interfaces used in the experiments, which are known as payloads, that fly on missions. Previously, there were no uniform guidelines and standards on design of computer displays and their usability such that each payload display might be significantly different. This disparity led to difficulties in training crew members to use displays and increased the training requirements to include aspects of varying displays. In the microgravity environment, the lack of standards led to crew member performance problems because of poor familiarity with display features or inclusion of display features inconsistent with crew member expectations. The PDD task will ensure common standards among payload displays.

The PDD task involves several HFE methods and tools including functional flow analysis, task analysis, and usability assessment. [4] Functional flow analysis, which is the first step in developing user scenarios for payload display design, gives designers an idea of what the display's purpose will be and what a crew member's interaction requirements will be. Task analysis, which also occurs during user scenario development, is used to create a detailed representation of human interaction with a system. Task analysis is the basic tool in design of displays, development of instruction manuals, preparation of training modules, and design of usability testing. All of this information is then fed into various stages of the usability assessment procedures, resulting in displays rich in human factors considerations. The outcomes are enhanced usability, decreased human error, improved human performance, and reduced mental and physical fatigue and stress.

Summary

In summary, human factors engineering (HFE) is being incorporated into the systems engineering process at MSFC in order to ensure increased safety, effective resource utilization, and adequately supported microgravity research endeavors. This paper presented HFE techniques and tools commonly used in MSFC human factors tasks and described some of these applications. The future of HFE at MSFC is promising in that Center management recognizes the utility of implementing this relatively new field of engineering. HFE will be significant in the next generation technology endeavors because HFE can provide data necessary for maintainability, supportability, and sustainability. As long as humans are in the advanced technology loop, appropriate consideration and accommodation of human function within the loop is a must. Regarding the microgravity environment of space, the human-centered design approach leads to safe, efficient, and productive missions.

References

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Appendix

See following page.

Biography

Dr. Mariea C. Dunn was the first African-American female to receive the Ph.D. degree in Industrial and Systems Engineering from the University of Alabama in Huntsville (UAH). Completing degree requirements in August 1995, Dr. Dunn's area of concentration was Manufacturing with minors in Applied Statistics and Human Factors. Presently, she is a NASA Administrator's Fellow assigned to George C. Marshall Space Flight Center in Huntsville, Alabama, is an Assistant Professor of Mechanical Engineering and is Associate Director of the Center for Energy and Environmental Studies at Southern University and A & M College in Baton Rouge, Louisiana. Dr. Dunn is the NSBE Region III Alumni Extension 1998-99 Academic/Technical Excellence Chair. She holds memberships in several other technical professional organizations.

APPENDIX

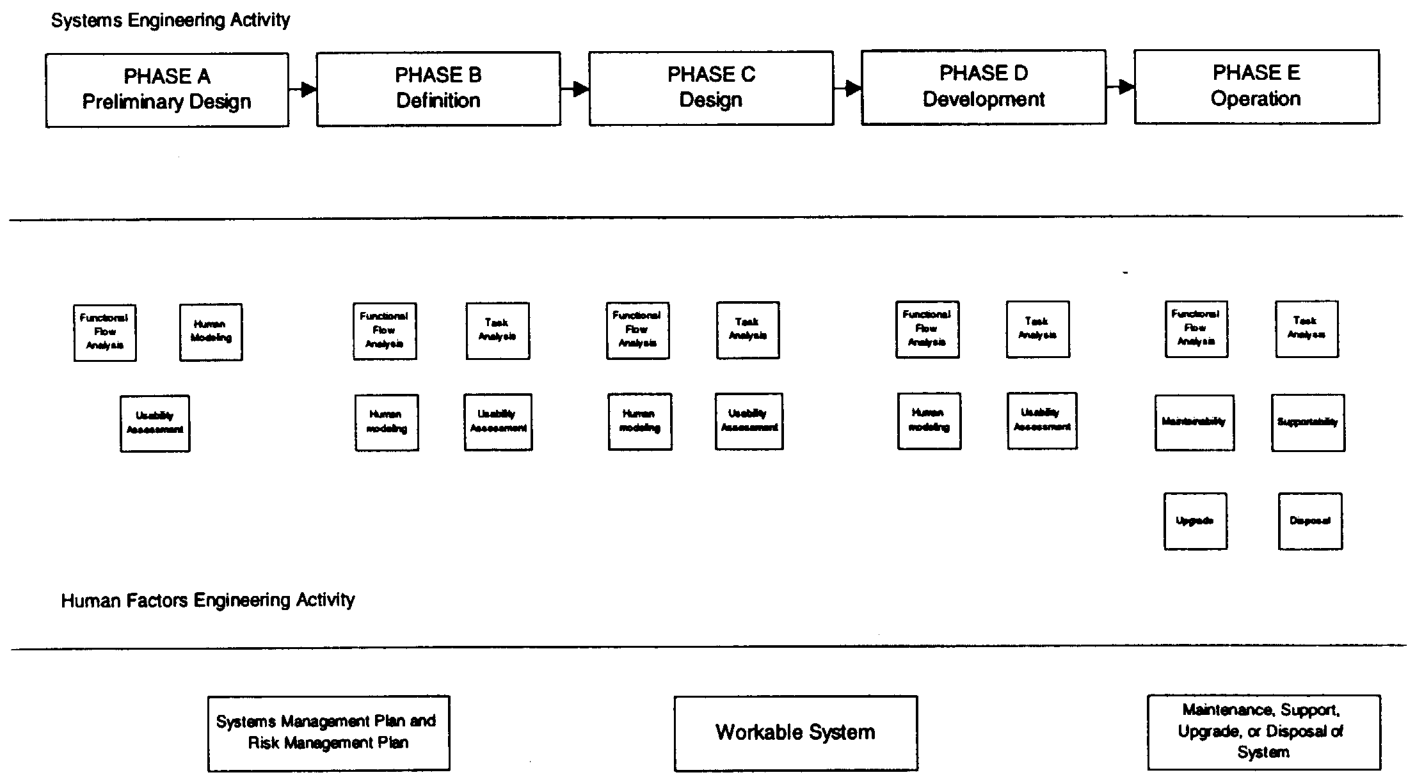

Figure 1. Systems Engineering Process Flow